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Life Cycle Impact Assessment—where we are, trends, and next steps: a late report from a UNEP/SETAC Life Cycle Initiative workshop and a few updates from recent developments

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Abstract
Purpose The paper provides a late report from the United Nations Environment Program (UNEP)/Society of Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative workshop "Life Cycle Impact Assessment (LCIA)—where we are, trends, and next steps;" it embeds this report into recent development with regard to the envisaged development of global guidance on environmental life cycle impact assessment indicators and related methodologies.
Methods The document is the output of the UNEP/SETAC Life Cycle Initiative's workshop on "Life Cycle Impact Assessment—where we are, trends, and next steps." The presentations and discussions held during the workshop reviewed the first two phases of the Life Cycle Initiative and provided an overview of current LCIA activities being conducted by the Initiative, governments and academia, as well as corporate approaches. The outcomes of the workshop are reflected in light of the implementation of the strategy for Phase 3 of the Life Cycle Initiative.
Results The range of views provided during the workshop indicated different user needs, with regards to, amongst other things, the required complexity of the LCIA methodology, associated costs, and the selection of LCIA categories depending on environmental priorities. The workshop's results signified a number of potential focus areas for Phase 3 of the Initiative, including capacity building efforts concerning LCIA in developing countries and emerging economies, the preparation of training materials on LCIA, the production of global guidance on LCIA, and the potential development of a broader sustainability indicators framework.
Conclusions These suggestions have been taken into account in the strategy for Phase 3 of the Life Cycle Initiative in two flagship projects, one on global capability development on life cycle approaches and the other on global guidance on environmental life cycle impact assessment indicators. In the context of the latter project, first activities are being organized and planned. Moreover, UNEP has included the recommendations in its Rio + 20 Voluntary Commitments: UNEP and SETAC through the UNEP/SETAC Life Cycle Initiative commit to facilitate improved access to good quality life cycle data and databases as well as expanded use of key environmental indicators that allows the measurement and monitoring of progress towards the environmental sustainability of selected product chains.

Keywords Capacity building · Global guidance · Life cycle assessment · Life cycle impact assessment · Rio + 20 voluntary commitments · UNEP/SETAC Life Cycle Initiative · Workshop report

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1 Introduction—the process

Since its launch, the United Nations Environment Program (UNEP)/Society of Environmental Toxicology and Chemistry

(SETAC) Life Cycle Initiative have invested significant resources in collaborating with its partners to refine life cycle methodologies according to the ISO14040/44 standards. In Phase 1, 2002–2006, of the Life Cycle Initiative, a materiality document on Life Cycle Impact Assessment (LCIA) was developed to scope the needs and produce a road map. Consequently, activities were carried out addressing various topics such as the environmental midpoint damage LCIA framework (Jolliet et al. 2004) and USEtox (Rosenbaum et al. 2008), the latter including (eco-)toxicity characterization factors. In Phase 2, 2007–2012, following the recommendation of the International Life Cycle Board (ILCB), the Phase 1 activities were continued and completed. In addition, new projects covering indoor pollution, water use in life cycle assessment (LCA), land use in LCA, and carbon footprint were carried out.

The ILCB is aware of how essential the efforts of the Initiative are to fill the gaps in the LCIA area and how limited they are considering the current needs. The efforts are complementary to relevant international, regional, and national activities, including those led by the European Commission (EC), International Organization for Standardization (ISO), Brazil, China, Japan, Switzerland, Thailand, USA, industrial associations, companies, and other institutions around the world. The current situation is that limited or no exchange occurs among the existing initiatives and therefore, there are high risks of duplication, misinformation, and inefficient use of resources, in terms of staff time and funds.

2 Methods—the workshop

The "LCIA—where we are, trends and next steps" workshop, held on 20 May 2011 in Milan, Italy, was attended by over 40 participants from industry, governments, consultancies, international organizations, and academia. It was a scoping workshop, aiming to provide an overview of the state of the art, new developments, future directions, gaps and needs, and a better understanding of what is expected or desired from the UNEP/SETAC Life Cycle Initiative with regards to LCIA in Phase 3. The workshop objectives were to (1) help strengthen the linkages of international LCIA actors globally, (2) develop a common understanding of where we are with regards to LCIA initiatives and trends, and (3) exchange and agree on next steps.

3 Results

3.1 Past and current LCIA activities of the UNEP/SETAC Life Cycle Initiative

Phase 1 of the UNEP/SETAC Life Cycle Initiative saw the development of four program areas: Life Cycle Management, Life Cycle Inventory (LCI), LCIA, and Life Cycle Cross-Cutting Activities. The aims of the LCIA work area were to identify user needs, to provide a clear picture of impact categories, to provide guidelines, to identify case studies and industrial partners, and to identify links to the other program areas. In order to achieve these aims, four Task Forces (TFs) were established. The four TFs produced 34 deliverables, ranging from publications to frameworks, models, and tools (Gloria 2011). TF 1and LCIA Information System, created the well-known midpoint–endpoint LCIA framework (Jolliet et al. 2004), see Fig. 1. Other examples of deliverables of the various TFs include the SETAC published book "*LCA of Metals*: *Issues and Research Directions*" (Dubreuil 2005) and the article "Key Elements in a Framework for Land Use Impact Assessment within LCA" (Milà i Canals et al. 2007) in "*TF 2 Natural Resources and Land Use*", and USEtox (Rosenbaum et al. 2011) in TF 3 Toxicity Impacts.

USEtox is being further developed in Phase 2, providing a stable interface between science and day-to-day application for life cycle toxicity assessment. Results have shown that there is an overall good agreement between the characterization factors (CFs) of spearheaded models, such as CalTOX, USES-LCA, IMPACT 2002+ (Jolliet et al. 2003), and USEtox. Future updates incorporate indoor exposure (from the UNEP–SETAC project), ionizing organic substances, modules for terrestrial and marine ecotoxicity (from the EC research projects Life Cycle Impact assessment Methods for imProved sustAinability Characterisation of Technologies (LC-IMPACT) and PROspective SUstaInability Assessment of TEchnologies (PROSUITE)), and improved CFs for metals (Rosenbaum 2011).

The improved CFs for metals was developed in another Phase 1 and 2 project of the Initiative conducted by the University of Toronto and collaborators at Radboud and Leiden Universities and RIVM in the Netherlands. The project developed a new framework and, subsequently, a model to estimate metal ecotoxicity in the context of LCIA, as metals have had a biased high ranking in terms of ecotoxicity in LCIA. The new framework incorporates a "bioavailablity" factor where the biologically active fraction of the chemical is multiplied by the fate and toxicity factors. The new CFs are up to three orders of magnitude lower than previous CFs and the ranking of metals also changed from the previous to new CFs (Diamond 2011).

Two other work groups, which have been active during the second phase of the Initiative, focused on "Water Use in LCA" (WULCA) and "Land Use in LCIA" (LULCA). WULCA has already completed both a midpoint–endpoint framework for water use assessment in LCA and a qualitative evaluation and review of water use accounting and assessment methods, LULCA has developed a framework for assessing impacts on ecosystem services (Koellner et al. 2011).

Overall, Phases 1 and 2 of the Life Cycle Initiative were considered successful. The initial phase, especially, brought

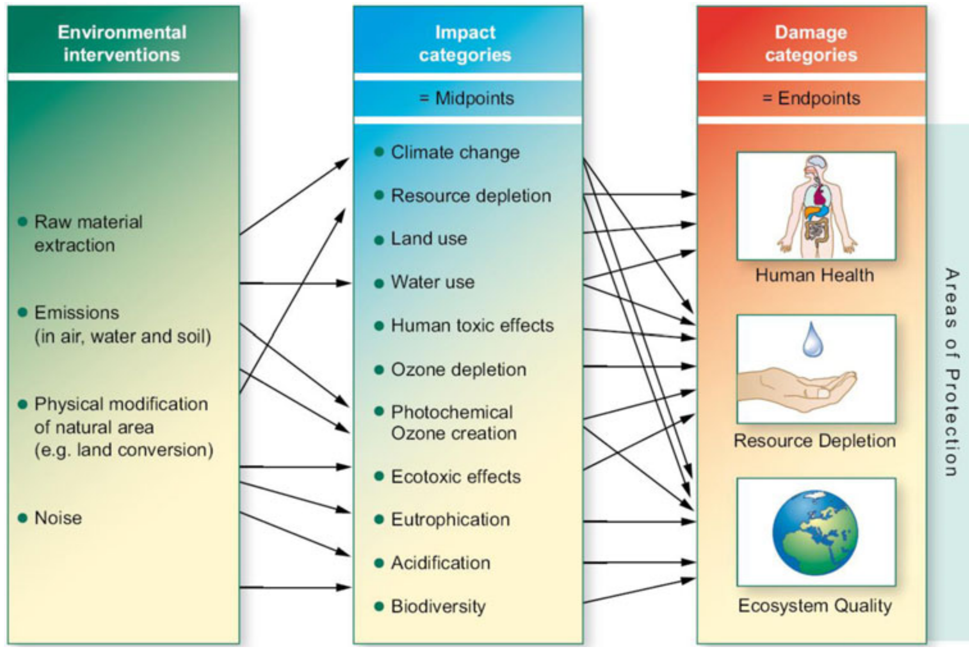

Fig. 1 UNEP/SETAC Life Cycle Initiative midpoint–endpoint LCIA framework (based on Jolliet et al. 2004)

together the community while numerous positive and well-received outputs were produced over the past ten years. However, there were some missed opportunities, for example, instances when work was left unpublished and it is, therefore, important to really push for publications and ensure consistent communication in the next phase (Gloria 2011).

3.2 Mapping academic and governmental LCIA activities in various regions

The UNEP/SETAC Life Cycle Initiative, described as an "International Life Cycle Partnership for a Sustainable World," is a diverse initiative, both in terms of geography and stakeholder groups (participants and sponsor affiliations, ranging from government to industry, consultancies, and academia). As mentioned earlier, the efforts of the Initiative aim to be complementary to ongoing activities in the field and its database of over 2,000 contacts is vital in maintaining connections and awareness of the current work. Various experts from around the world presented a snapshot of the international state with regards to methods and more general research developments on LCIA.

3.2.1 Asia

LIME (Japan) Japan developed a LCIA Method based on Endpoint modeling (LIME). The second national LCA project, LIME2, was completed from 2004 until 2006, encompassing 15 impact categories, improved representatives of weighting factors, and a list of LCIA factors including statistic values based on uncertainty analysis. The LIME2 Guidebook (Itsubo and Inaba 2010) provides the list of LCIA factors, the case studies, and the methodology. The geographical range of LIME was extended to allow the development of LCIA methodology for other Asian countries including Mongolia, China, South and North Korea, Laos, Myanmar, Cambodia, Philippines, Thailand, and Vietnam; "LIME-Asia" (Inaba 2011). Currently, a world model is under preparation (Itsubo 2012).

SIMPASS (Singapore) Singapore IMPact ASSessment (SIMPASS) is an academic study which is reviewing and adapting existing LCIA methods for application to Singapore's environmental Areas of Protection (AoP) with the overall objective to enhance the long-term relevance and usefulness of LCA studies in Singapore. Singapore, like other countries, is unique and faces its own mixture of environmental threats and problems. The main environmental priorities specific to Singapore, with its limited surface area and high population density, include water resources, waste, and pollution (Tan 2011).

3.2.2 Europe

European Commission Joint Research Center The European Commission Joint Research Center (EC JRC) is a key actor in Europe and the funding body of various EU LCA-related projects. One project is focusing on the comparison of existing characterization models. The project considers only original approaches and uses scientific criteria, such as completeness of scope, environmental relevance, etc., to score each midpoint and endpoint models separately on a letter scale. The resulting scores were interpreted and recommendations were drafted (Hauschild 2011; Sala et al.

2011). The EC JRC also has two publications focusing on LCIA as part of the International Reference Life Cycle Data System (ILCD) Handbook: LCIA—Framework and Recommendations (EC JRC 2010b), and LCIA—Analysis Document (EC JRC 2010a).

Ecological Scarcity (Switzerland) The ecological scarcity method assesses environmental impacts from a national (regional) policy perspective, using, as a basic concept, the distance to target method combined with modeling of the environmental mechanisms up to midpoint (characterization) level. The method is simple, flexible, and adaptable, requiring mainly national statistics on emissions and resources and national or regional environmental policy goals. The method is applied by both governments, like Switzerland, and companies, like Volkswagen (Frischknecht 2011).

BP X30-323 (France) The French government is very much interested in improving the sustainability of their consumption patterns and is using various methods to facilitate this desire, including ecolabels, ecodesign, and other LCA-based tools. BP X30-323 is a general calculation methodology, adopted in 2009 and revised in 2011, providing a general methodological framework for the quantification of environmental impacts of mass market products. The aim is to create simplified tools, including an online database and calculator (Chevassus 2011).

LC-IMPACT Life Cycle Impact assessment Methods for imProved sustAinability Characterisation of Technologies (LC-IMPACT) is an EU project under the 7th Framework Programme, aiming to develop and apply LCIA methods for a range of midpoint and endpoint categories representative of the global scale. The various work packages of the project focus on methodology development concerning resource use impacts, ecotoxicity and human toxicity, and nontoxic pollutant impacts. The project uses three case studies to illustrate the application of the methods: food production, paper production and printing, and automobile production and operation (Hellweg 2011). As part of LC-IMPACT training material will be developed (Itsubo 2012).

ReCiPe (Netherlands) ReCiPe is a LCIA method that provides both midpoint and endpoint CFs, while including uncertainty using the cultural theory and three different perspectives representing a common vision on a set of choices: individualist (short term), hierarchist (often considered the default model), and egalitarian (long term). ReCiPe was developed in the Netherlands and is currently included in the new ecoinvent database and linked to various EU projects like LC-IMPACT, the ILCD Handbook, and USEtox (Heijungs 2011).

3.2.3 America

US EPA—TRACI (USA) Relevant research is being conducted in the USA focusing on various topics, including renewable energy and fuels and water. The “Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts” (TRACI) model, is updated on a more or less regular basis (Bare 2011).

IMPACT WORLD+ An international consortium is currently developing a global regionalized LCIA method known as IMPACT WORLD+, which will aim to account for regional specificity whilst maintaining a global coherence. Products and processes are part of a global economy and therefore, impacts are occurring all around the world. As generic CFs have a higher uncertainty related to the spatial variability, IMPACT WORLD+ uses regional CFs when possible, i.e., when the location is known; generic CFs with a corresponding spatial variability are used if unknown. The results are presented at three different levels: midpoint level, AoP level, and an operational intermediary level keeping climate change and water impacts as separated categories (Bulle 2011). IMPACT WORLD+ was launched in 2012 and now ensures modeling the entire world in a consistent way (Itsubo 2012).

Brazil LCA in Brazil dates back to the year 2000, however the majority of LCA-related efforts are focused on LCI therefore, resulting in a limited number of LCIA activities. A main reason is the lack of funding, for life cycle work in general, but especially for LCIA as the majority of funds are used for LCI. Other reasons include data, which is either not available or not standardized; expertise, with the majority of LCA experts in Brazil coming from an engineering background and therefore not as connected to toxicity impacts; and having decentralized initiatives. There is a clear need to raise awareness concerning LCIA and to both regionalize CFs, following the regionalization of LCIs, and to develop CFs for impact categories relevant in the region (Ugaya 2011).

3.3 Corporate approaches

Besides academic and governmental initiatives, there has also been an increasing uptake of the LCA methodology within businesses and industry due to pressures from both downstream and upstream actors, regulations, and the need to maintain competitiveness. However, there are many different needs depending, amongst other factors, on the type of business or industry, their ultimate goal, and the size of the company. One example is the EU chemical industry of which 96 % is small and medium sized enterprises (SMEs) and their limited resources make it challenging for them to fully benefit from LCIA. The specific needs of chemical

companies concerning LCIA clearly vary depending on their size, with the larger companies requiring more accurate assessment methodologies integrated into their sophisticated LCA tools that will increase the scientific credibility of LCIA. The SMEs, on the other hand, require access to accurate, easy to use, low-cost LCA tools that can increase their up- and downstream knowledge (Russell 2011).

As the availability of resources is a significant factor, it was stressed that a balance between the data and the methods required and the costs to support them, needs to be found. The reality highlights that LCI data production is ad hoc, costly, and not directly linked to business processes or practices. Currently, industry can barely support the number of impact categories available at the moment. One question to consider is whether more LCIA categories are desired or rather fewer LCIA categories but with more and better quality data (King 2011). The availability of different methodologies providing different results also increases the skepticism towards LCIA and jeopardizes the uptake (Russell 2011). Communication and harmonization between the various actors is encouraged. Examples of more specific challenges for LCIA in the consumer goods sector include the large number of data gaps, especially for the agricultural sector and its products, and the ability to obtain the right quality of information for the type of decision or intended use of the data. The consequences of these two points are the increasing need and challenge to update the data, plus the associated increasing costs (King 2011).

Renault is using an LCA methodology and the LCIA categories are chosen using four main pillars: adequacy, feasibility, robustness, and consistency. The five impact categories used are abiotic resource depletion, global warming 100 years, acidification, eutrophication, and photochemical ozone creation (Morel 2011). The methodologies and impact categories used might vary for different product groups depending on their relevance, the main objective, and other factors. However, what various industry and government representatives agreed upon is the need for tools which are accessible and simple and easy to use and communicate to the various stakeholders (Chevassus 2011; Jaš 2011). Another overall trend within the industries is that the main priority is no longer only carbon and greenhouse gases, but is shifting towards other environmental areas such as water, land, metals, and minerals.

3.4 Emerging indicators

As indicated, not only by industries but also by the ongoing efforts in governments and academia, the focus is no longer only on carbon. Other environmental indicators are emerging to the forefront again, including water, toxicity, and biodiversity. One of the oldest sum parameters is Cumulative (primary) Energy Demand (CED), used in the time of the "proto-LCAs," being part of a precursor impact assessment (Klöpffer 2011). The LCA community came with arguments pro-CED, for example, arguments for including CED as a sum parameter in LCI (Klöpffer 1997) and Finnveden and Lindfors (1998) highlighted that the uncertainty of CED data is smaller than for other indicators. However, neither ISO 14040 nor ISO 14044 refer to CED.

Concerning the more recent, emerging indicators, the Life Cycle Initiative has already developed itself in the area of water, land, and toxicity via WULCA, LULCA, and USEtox. The focus on water, particularly, is not expected to reduce in the near future, especially since the total water that is actually available and accessible will probably not be enough come 2030 (Aldaya 2011). The Water Footprint Network (WFN) provides another aspect to a possible water sustainability indicator: the Water Footprint (WF), considered by WFN to be an indicator of freshwater use, looks at both direct and indirect water use of a consumer or producer. A pilot study by Unilever and WFN compared the WF and LCA approaches by assessing the water use and impacts of tea and margarine. Results indicated that there were great similarities between the WF and LCA methodologies; the main difference being related to the boundary setting. There are many opportunities for collaboration between the LCA and WF communities as both have a common need for data on consumed water in industrial processes and there is an additional need for indicators for water scarcity and other potential water-related impacts (Aldaya 2011). As there are various significant actors in the area of water sustainability, including ISO, WULCA, and WFN, there is a need to clarify and communicate clearly the different parties and their work and to combine efforts. It would be ideal to use the strengths of the various communities with regards to methodology development. There are already a lot of common ideas, especially concerning the accounting and inventory aspect of water consumption. The strengths of the various methods available need to be highlighted in order to indicate in which application a method has its strength and can therefore be meaningfully applied.

The Life Cycle Initiative has been involved in various different areas, including toxicity (USEtox), water use in LCA (WULCA), land use in LCA (LULCA), and carbon footprint. However, ecosystem management, one of UNEP's "key thematic environmental areas" and an area of increasing interest to the public, government, and industry, has not yet been sufficiently addressed in the Initiative's work. The findings of the Millennium Ecosystem Assessment (2005) report indicate inherent links to the LCA, as a number of drivers for biodiversity change, e.g., climate change, pollution, habitat loss, are addressed by LCA, see Fig. 2. The exceptions of the main drivers that are not addressed are invasive species and overexploitation; the latter being discussed in LCA literature but not systematically

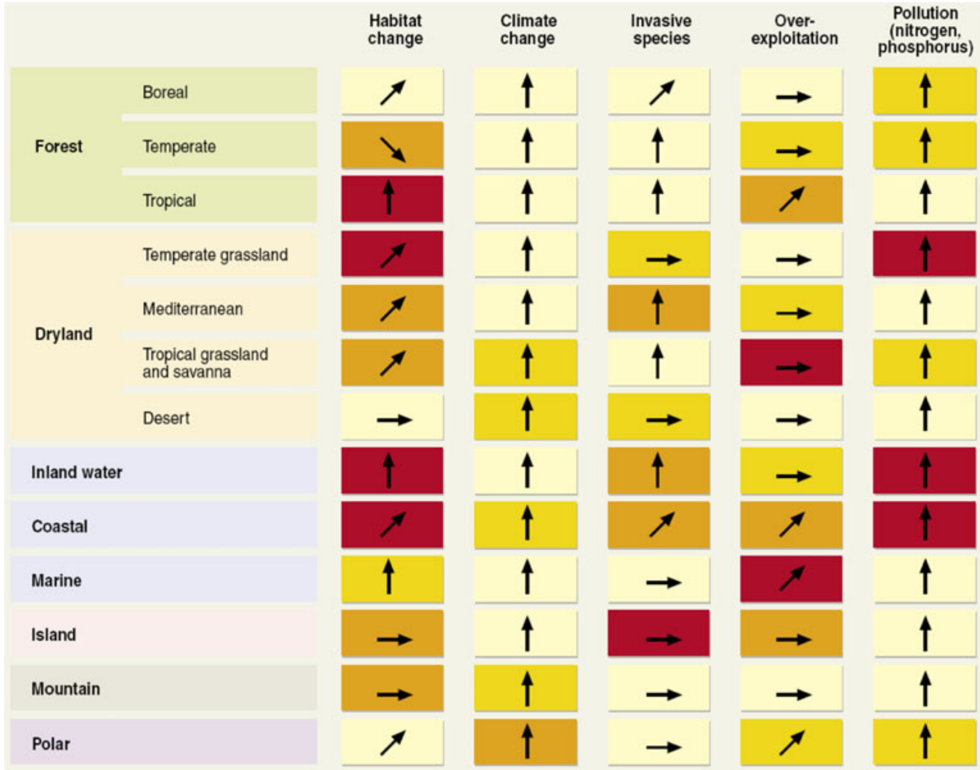

Fig. 2 The main drivers of biodiversity change according to the Millennium Ecosystem Assessment (2005) report. The *cell color* indicating the impact on biodiversity change in the biomes listed over the past 50–100 years; *darker color* indicating increased severity. The *arrows* indicate the trend of impact of the driver on biodiversity, e.g., horizontal indicating a continuation of the current level of impact. Currently, LCA addresses well the pressures on biodiversity due to climate change and pollution, partially those due to habitat change through land and water use and in a limited way overexploitation, but not at all invasive species. (Millennium Ecosystem Assessment 2005)

considered. Even though there is a great correlation, there is also a lack of communication between the LCA and MA community, and therefore, a new project idea was developed. The project's overall objective is to increase the visibility for decision makers, in particular from industry and business, concerning impacts on ecosystems and biodiversity due to goods and services. UNEP and ETH-Zürich have been collaborating on the project, with PhD students developing methodologies for LCA to assess the biodiversity loss that is associated with agricultural land and water use (Sonnemann 2011).

4 Conclusions—next steps

The UNEP/SETAC Life Cycle Initiative's workshop on "LCIA—where we are, trends, and next steps" provided an overview of the past, present, and upcoming work in the LCIA area. Various views were provided from different regions and countries, which indicated the continuous need for capacity building, harmonization, communication, and raising awareness especially in emerging economies. The regionalization of characterization factors towards a global scope was also highlighted to be important. However, needs vary across regions, depending on the current status of the LCIA-related work done and the local environmental issues and priorities.

However, the needs and expectations do not only vary according to geographies, but also depending on the needs of industries as users. Various industries use different indicators corresponding to their needs and priorities. A main challenge is finding the balance between the needs of smaller businesses and organizations for simple and low-cost tools, and the needs for larger organizations, where more sophisticated models result in increased credibility. With the development of more tools, models, impact categories, and characterization factors also come increased confusion, and therefore the risk of decreased uptake of the LCA tool. Aside from the variations between geographic regions, industries, and users, it is clear that there is a need for capacity building on LCIA, especially in emerging economies, and global guidance within a flexible and adaptable framework.

The workshop also confirmed that carbon is not the only issue to consider when assessing the environmental impacts of products, as many countries, industries, and organizations are moving beyond carbon, starting to also direct their focus towards water, toxicity, and biodiversity. Future work might therefore center on the development of a broader environmental life cycle based sustainability indicators framework, into which a wide range of impacts and focus areas can be embedded. Such a global flexible sustainability indicator framework would consist of efficiency, midpoint, endpoint, and management level indicators for LCA. The question on the role of efficiency indicators and the role of and relation to the ISO standards would have to be addressed in such a framework, as well as the topic of performance versus management indicators.

The above mentioned suggestions on capacity building and harmonization have been taken into account in the strategy for Phase 3 of the Life Cycle Initiative in two flagship projects, one on global capability development on life cycle approaches and the other on global guidance on environmental life cycle impact assessment indicators. In addition, the Initiative will continue to address its current priority areas for LCIA method development (toxicity, water use, land use, etc.), incorporating as fast as possible emerging challenges such as biodiversity. Communication and publication of deliverables is essential in order to ensure that the work completed becomes visible and interlinks with ongoing efforts. An overview document and related training material on Life Cycle Impact Assessment would be very helpful in organizing capacity building events in developing countries and emerging economies, which the workshop highlighted is urgently required to promote and advance the uptake of life cycle approaches worldwide. The LC-IMPACT activities related to training could be very helpful in this respect.The topic of global guidance is expected to be addressed in a process similar to the global guidance (principles) on LCA databases (Sonnemann et al. 2011; Sonnemann and Vigon 2011)and has been taken up by UNEP in its Rio + 20 Voluntary Commitments: The UNEP and the SETAC through the UNEP/SETAC Life Cycle Initiative commit to facilitate improved access to good quality life cycle data and databases as well as expanded use of key environmental indicators that allows the measurement and monitoring of progress towards the environmental sustainability of selected product chains (UNCSD 2012). In the context of the flagship project on global guidance on environmental life cycle impact assessment indicators first activities are being organized and planned. An International Symposium on Life Cycle Impact Assessment—Towards development of global scale LCIA method was organized by the Tokyo City University and supported by the UNEP/SETAC Life Cycle Initiative on November 2012 in Yokohama, Japan (Itsubo 2012). The next step is a LCIA workshop back to back to the SETAC Europe meeting in May 2012, in Glasgow, UK. The workshop will also take advantage of efforts started by SETAC, particularly in North America, to set up a global process for further harmonization in LCIA methods. Regionalization is a key aspect of this new work stream and participation of experts from all regions of the world, in particular from developing countries, is encouraged. The full workshop report can be obtained from the new UNEP/SETAC Life Cycle Initiative website at http://www.lifecycleinitiative.org/.

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